MET 4300

Lecture 26 Hailstorms (CH20)

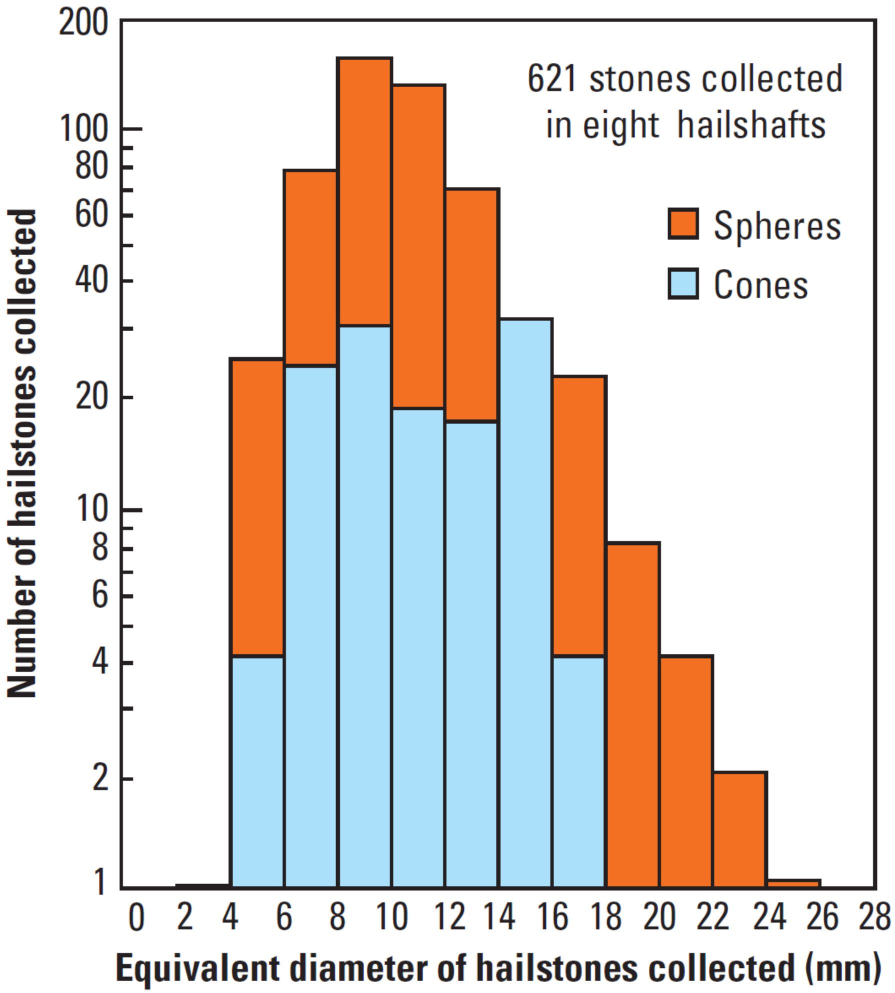
Hail Impacts

Brush CO, 3 hours after a hailstorm

Window damage during the Forth Worth, Texas, March 28, 2001 (plywood replaced windows due to hail damage. Hail size upto 3 inches)

- $900M per yr in property damage in the US
- $140M per year in crop damage in US
- 2001, worst year, $2.5B property damage due to one hailstorm: the Tri-State hailstorm.
- Human fatalities are rare: only 50 injuries per year in US; total 4 deaths per decade; Nepal 29 deaths in 1990, China 200 deaths in 1932, India 200 deaths in 1888.

Sampled Distribution of Hailstone Sizes



Under 8 hailshafts in storms in eastern CO

Potential for damage increases with size and fall speed:
D=2cm hails will fall at Vt=20 m/s (45mph) in still air;
D=5cm, Vt=46 m/s (103 mph)

Largest hailstone: d=20.3 cm (8 inches)

Most are about 1 cm diameter

D>2.5 cm is relatively rare.

> 5 mm to qualify as hail
Smaller are graupel

Hailstone Size Descriptions by Meteorologists

Pea sized --- 0.5 cm
Marble sized---1 cm
Golf ball sized---4 cm
Tennis ball sized – 6cm
Baseball sized---7 cm
Grapefruit sized---10 cm
Softball sized---12 cm
Quarter coin sized = 2.5 cm = 1 in

A spiked hailstone compared to a $20 bill

Record Hailstones: diameter, weight, & circumference

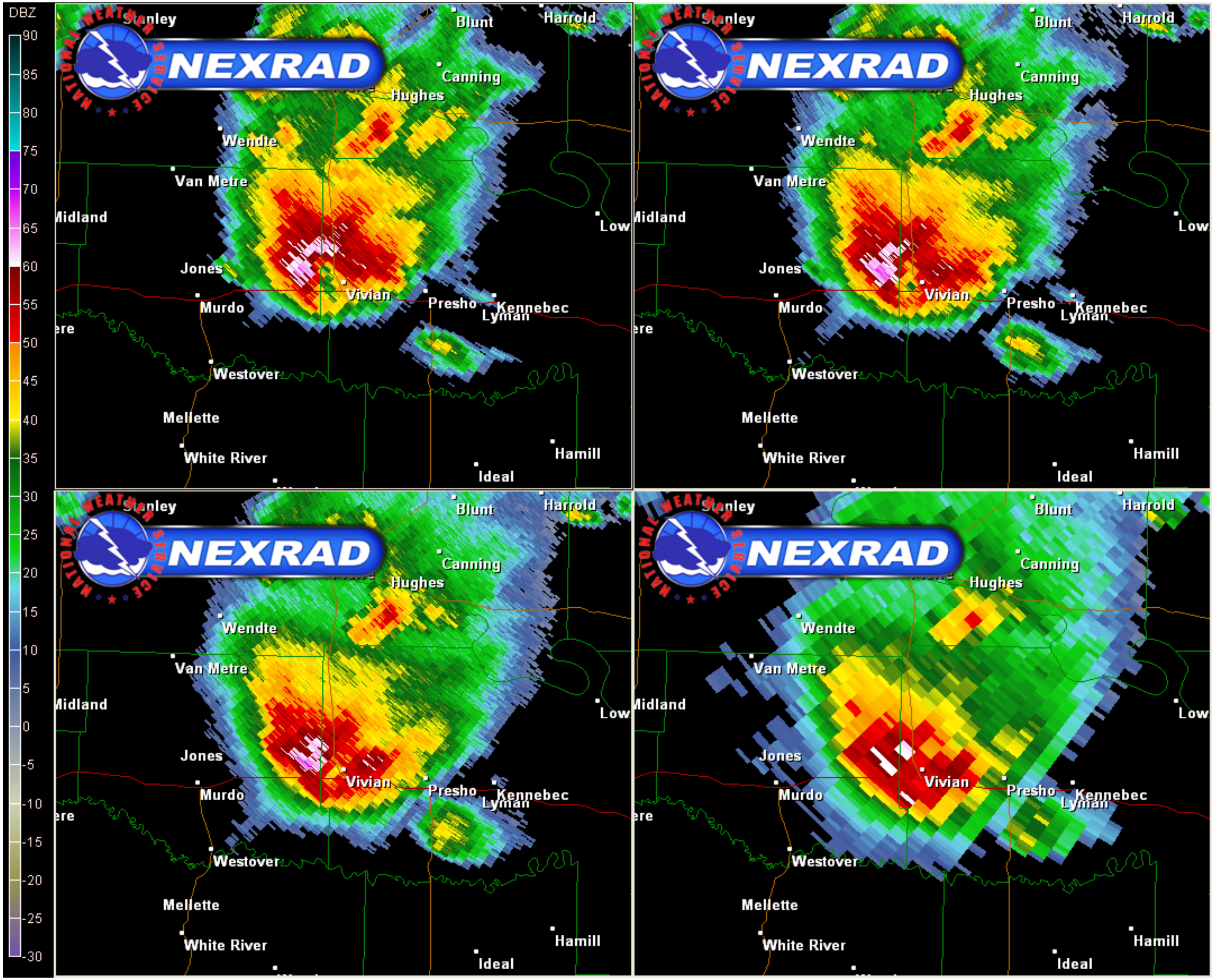
Current record holder (the white cast) for diameter & weight): Vivian South Dakota, 23JUL2010: 8 inches in diameter, 1.9375 lb, 18.62 inches in circumference.
Former record holder for diameter , weight & circumference (next to the grape fruit): Coffeeville Kansas (record until 2003)

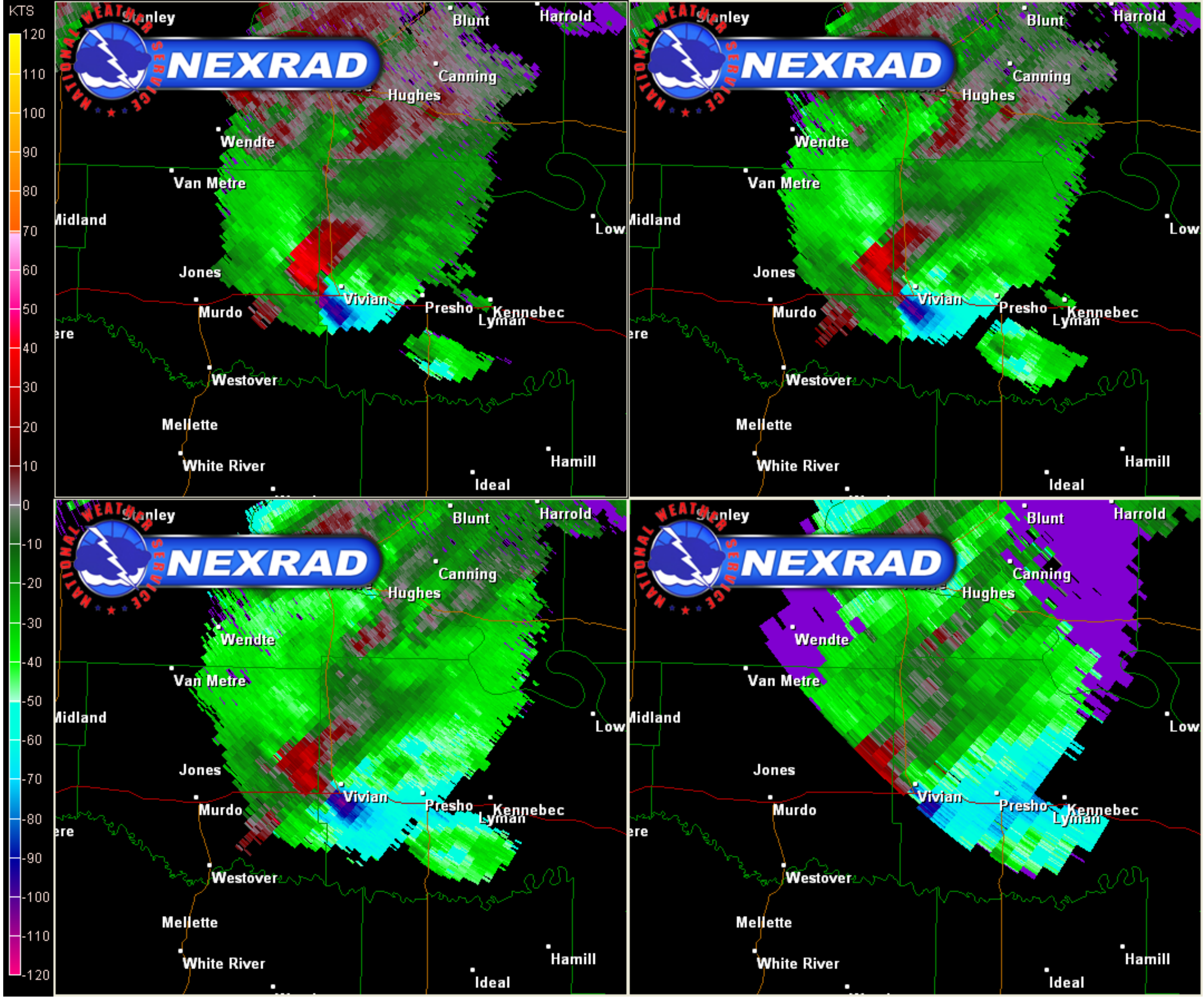
Current record holder for circumference):

Aurora Nebraska, 22JUN2003
7 inches in diameter, 18.75 inches in circumference, 770 gram

Record Setting Hail Event in Vivian, South Dakota on July 23, 2010

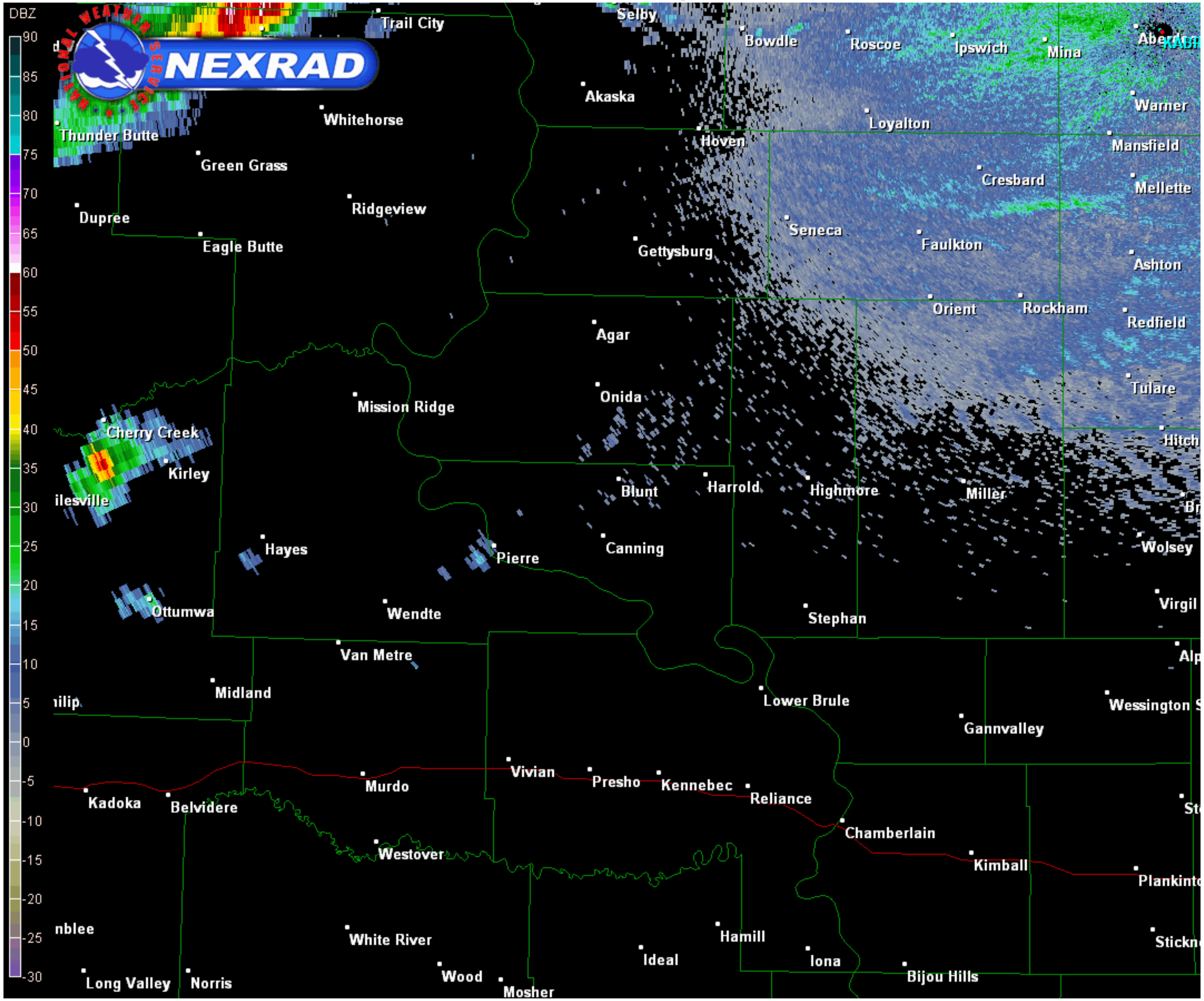
4 Panel Radar Reflectivity valid at 2258 UTC (0.5, 0.9, 1.3, 1.8 degrees)





4 Panel Storm Relative Velocity valid at 2258 UTC (0.5, 0.9, 1.3, 1.8 degrees); Initial estimates indicate that the updraft strength in the Vivian hail storm likely ranged from **160-180 mph**!

Radar Loop



DBZ
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NATIONAL WEATHER SERVICE
NEXRAD
Trail City
Selby
Bowdle
Roscoe
Ipswich
Mina
Akaska
Whitehorse
Thunder Butte
Hoven
Loyalton
Warner
Mansfield
Green Grass
Cresbard
Mellette
Dupree
Ridgeview
Seneca
Eagle Butte
Gettysburg
Faulkton
Ashton
Orient
Rockham
Redfield
Agar
Tulare
Onida
Mission Ridge
Cherry Creek
Hitch
Kirley
Blunt
Harrold
Highmore
Miller
ilesville
Hayes
Pierre
Canning
Wolsey
Ottumwa
Wendte
Stephan
Virgil
Van Metre
Midland
Lower Brule
Wessington
Gannvalley
Vivian
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Kennebec
Reliance
Murdo
Kadoka
Belvidere
Chamberlain
Westover
Kimball
Plankint
nblee
White River
Hamill
Ideal
Iona
Stickn
Bijou Hills
Long Valley
Norris
Wood
Mosher

Hail Formation (in T-storms with very strong updrafts extending well-above the freezing level)

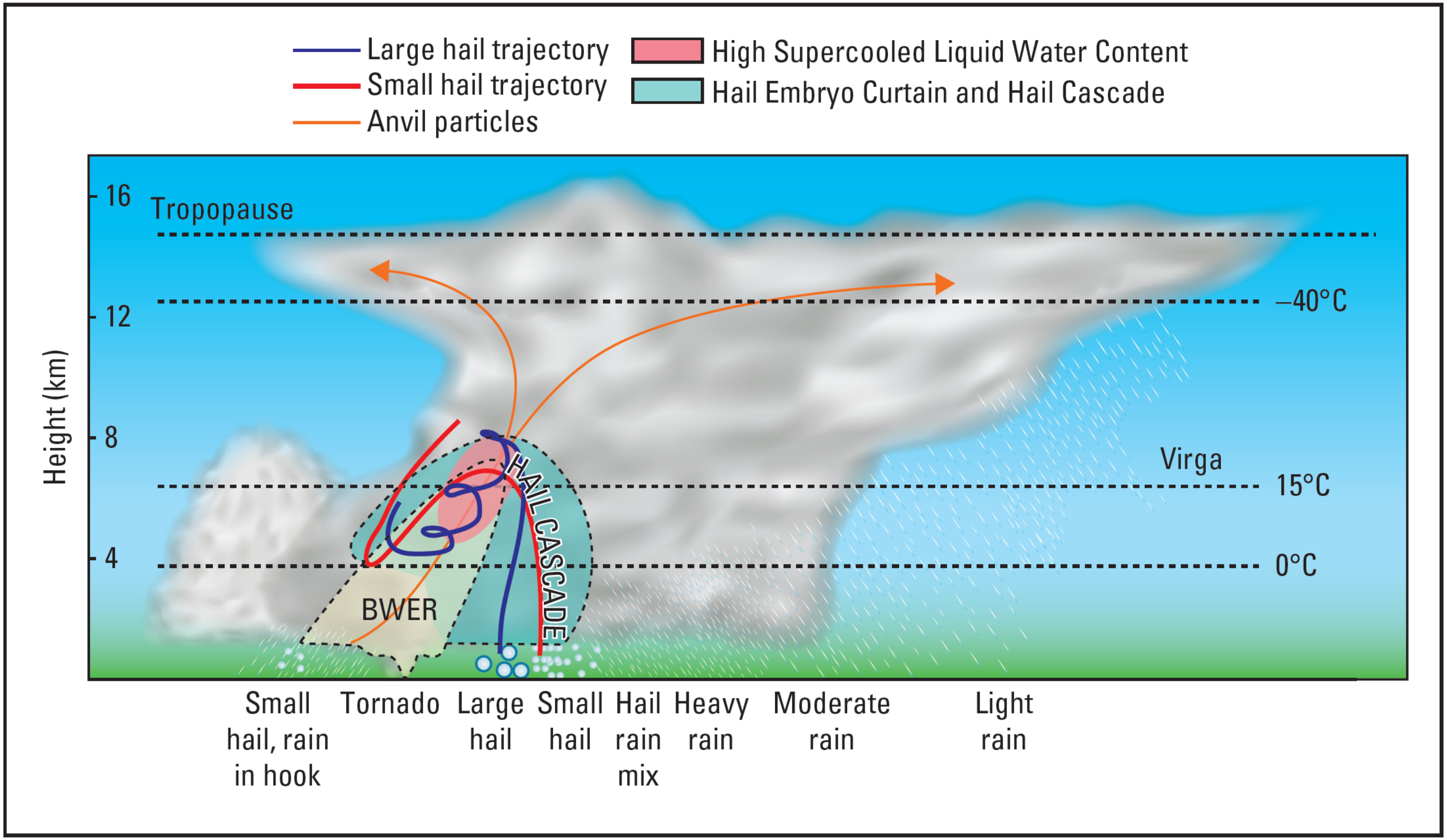
- Research tools:
  - Limited aircraft Doppler radar data by an armored T-28 aircraft
  - Simulating hail growth in lab wind tunnels
  - Models and ground-based multiple Doppler radar wind fields
- Hail growth occurring in two steps:
  - Hail embryo formation. Hail embryos: ice particles at the center and as cores for initial growth
  - Hailstone formation. Hailstones: the final large stones composed of hard or spongy ice
- Each step requires one up-down cycle through the storm clouds.

Hail Embryo Formation

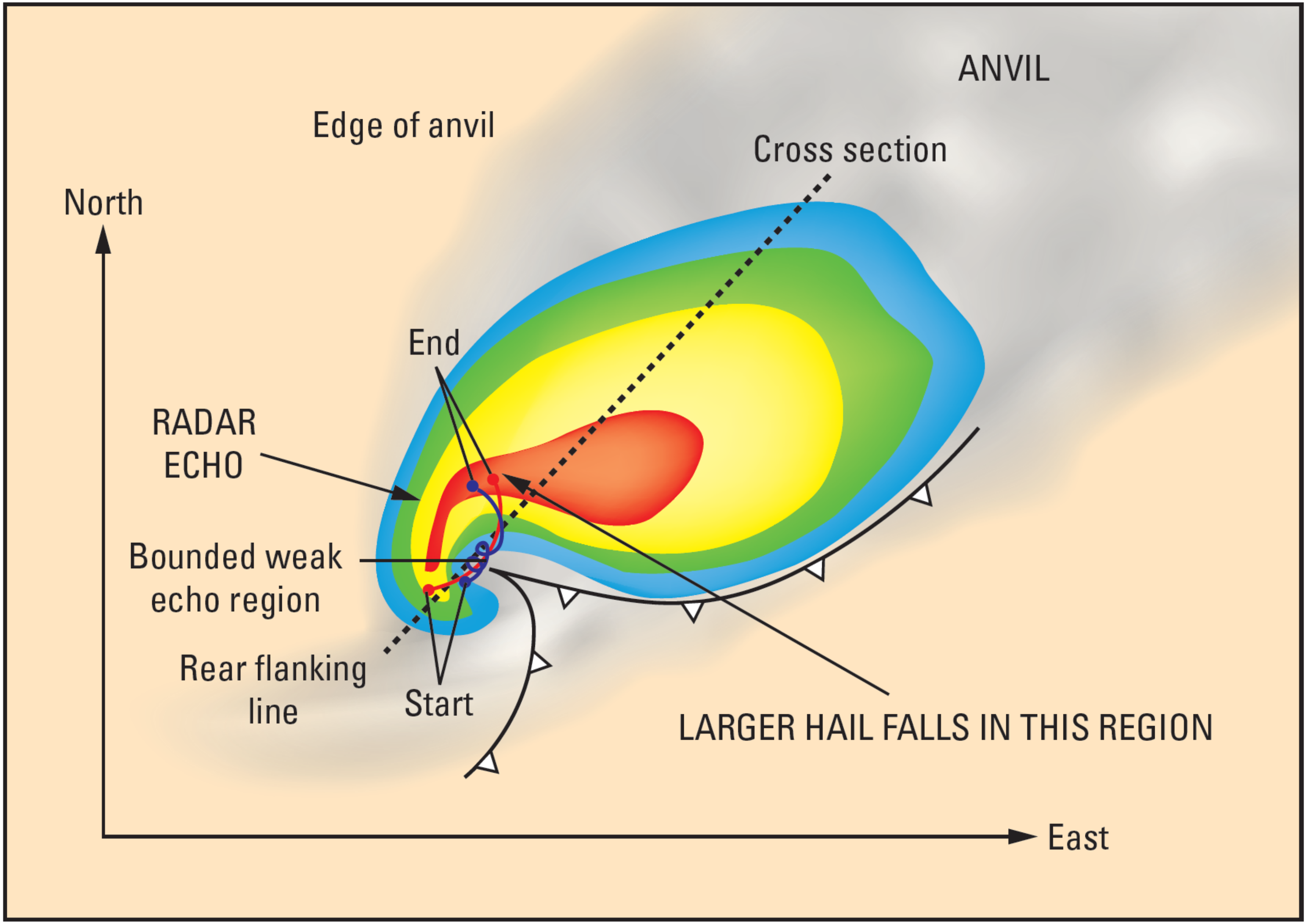
- Updraft region, also called ***bounded weak echo region (BWER)*** *or* ***echo-free vault*** is filled with small supercooled cloud water droplets (~0.02 mm in diameter) between **0^{o}C** and **-15^{o}C. BWER is the center of of the hook echo in supercells.**
- Because the updraft is so strong that there isn't enough time for warm rain processes and glaciation

  For example, w=30 m/s, a small droplet can up 3km in 2 min
- Also because of absence of ice nuclei, ice can finally nucleate only at temperatures < **-15^{o}C**
- Ice particles that form in the stronger parts of the updraft are carried upward & ejected into the anvil (thin/orange trajectory)
- Some ice particles near the periphery of the updraft and in weaker updraft cells forming in the flanking line of clouds along RFD begin to fall and grow by collecting supercooled cloud droplets (red trajectory). They form graupel (soft ice particles with diameter ranging between 1-5 mm) that becomes ***Hail Embryos***
- These fall around the updraft in the circulating wall cloud
- The largest concentration of graupel particles surrounding the BWER form an ***embryo curtain****.*

Supercell Hailstorm in Cross Section (from SW to NE)



Supercell Hailstorm in Plan View

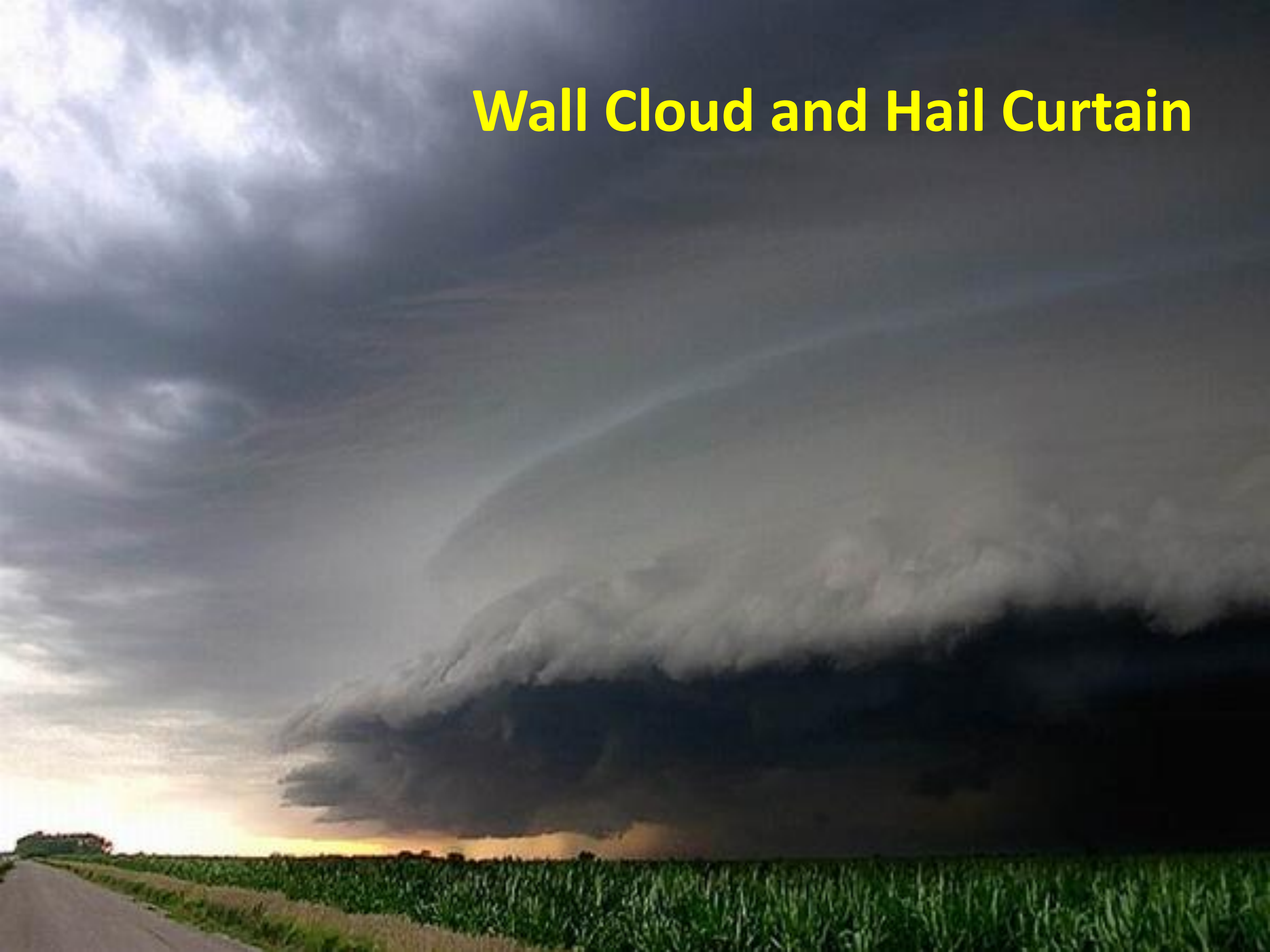


Hailstone Growth: Typical Trajectory (Red)-- small hailstones

- Some of the graupel particles in the embryo curtain are swept back into the updraft circulation by horizontal winds.
- Once in the updraft, they grow rapidly and experience alternating cycles of wet ($T >= 0^oC$) and dry ($T < 0^oC$) accretion of supercooled water, producing layers of clear and white ice.
- Because the water content of the updraft is large they can get really big
- Those particles located in the updraft but close to its periphery have ideal trajectories for hail growth (Vt equal or slightly < w, will rise slowly or "floating "while collecting supercooled water droplets).
- Winds aloft eventually carry the stone NE side of the storm, and the stone begins to fall.
- Hail cascade: flanks the updraft on the east and NE of typical supercells, and appears visually as a white curtain of hail.

Hailstone Growth: Modified Trajectory (Blue)-- large hailstones

- These graupel particles enter the updraft along the periphery of the supercell's hook echo.
- These particles grow within the updraft, spiraling upward within the storm's rotating mesocyclone.
- Exposed to exceptional liquid-water contents while "floating" in the storm's rotating updraft, these stones can grow to sizes of 5 cm (2 in) or larger and fall close to where the hailstone embryos first entered the updraft.
- Stones that float and spiral within an updraft core of the mesoscyclone apparently have the greatest potential to grow to exceptional size—the legendary grapefruit- and softball-sized stones reported in the most violent of hailstorms.


Wall Cloud and Hail Curtain

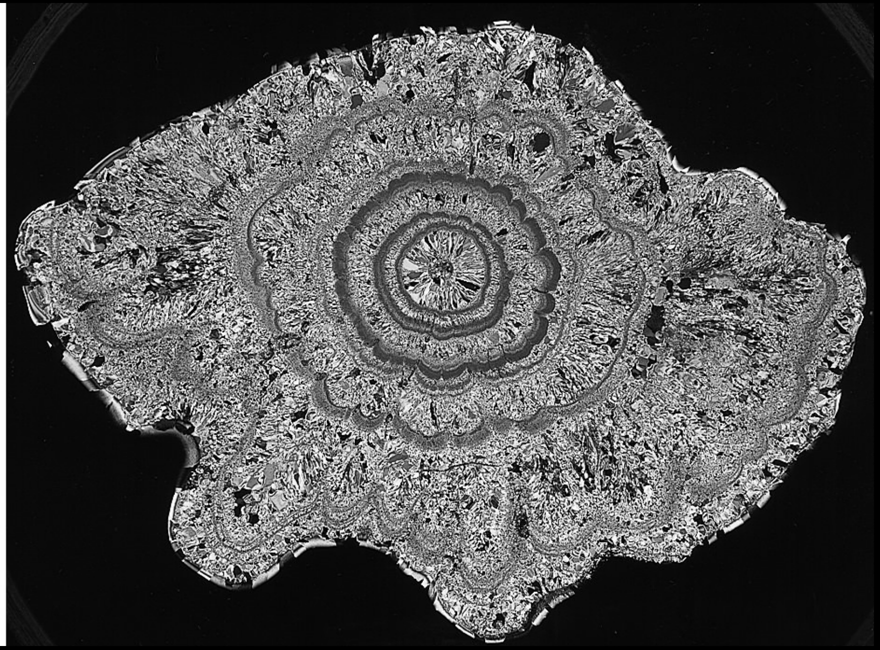
Hail Curtain

Two Modes of Hail Growth: Dry growth and wet growth

- **Dry Growth Regime**: Considering a hailstone growing at T< 0^oC. As each cloud liquid drop freezes on the surface of the hailstone, latent heat is released. If the surface of the hailstone remains T< 0^oC, the supercooled droplets will freeze and the stone's surface remain dry.
- **Wet Growth Regime**: If the latent heat will raise the temperature to T> 0^oC (so much droplets freezes), the freezing will be delayed. Water can spread across the surface and drain into porous regions. This mode of growth is called the wet growth regime.
- As hailstones pass through thunderstorms, they may grow by one mode then the other. Ice is clearer in wet growth and opaque/milky in dry growth (tiny bubbles of air trapped in the ice during rapid freezing).
- **Early explanations of hail growth** were heavily based on the notion of recycling, even to the point of including multiple vertical "loops" in the hail trajectory. This is due to the fact of the internal layering as shown in the next slide. However, now it's known that the turbulent motion in the updraft cause the hail embryos to accrete supercooled liquid at varying rates, which is the primary reason of hail's layered structure (alternating between dry growth & wet growth).

Anatomy of a BIG Hailstone

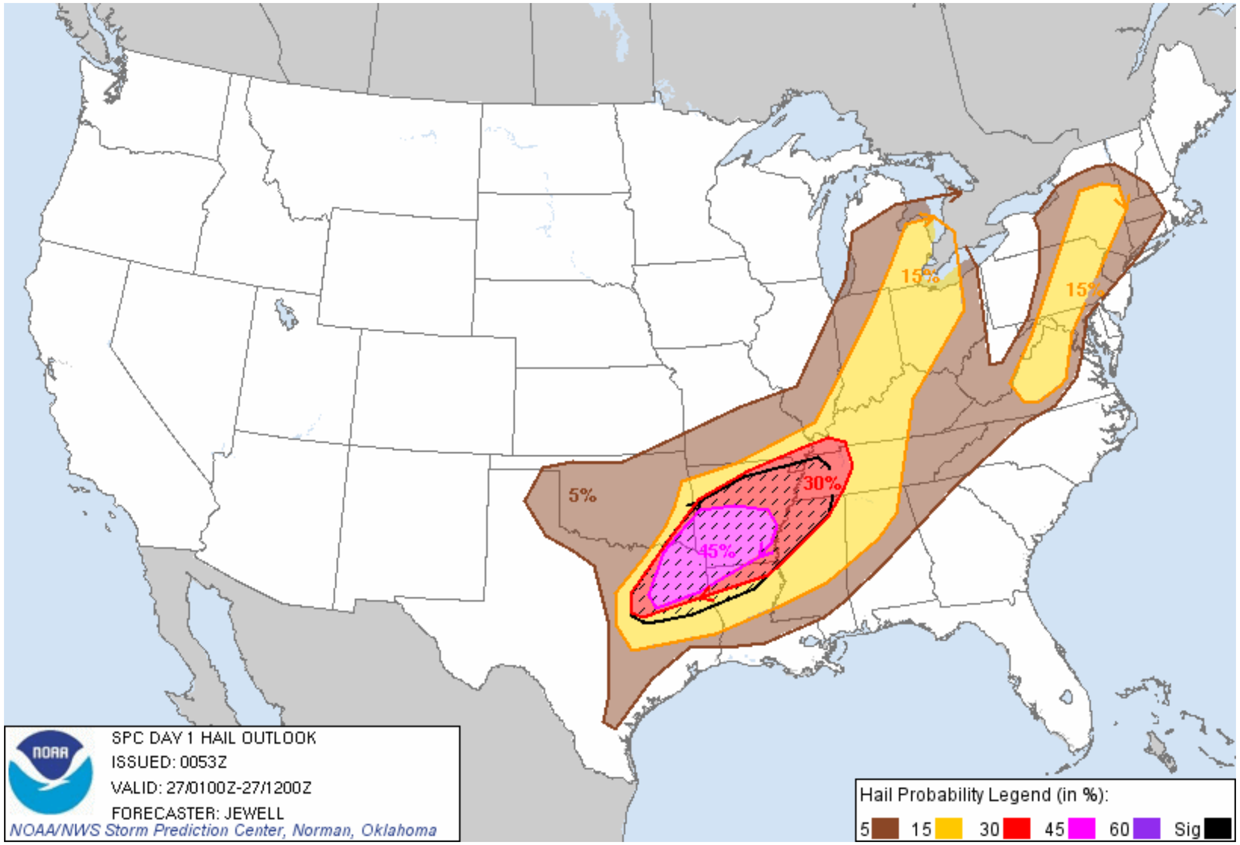
A thin slice through a large hailstone (long dimension is 5.6 inches) **shown in natural light**: illustrates the layers of alternate air bubble density indicative of wet & dry growth modes.



The same slice of the hailstone shown **in cross-polarized light** to show the crystal structures.

Forecasting Hail

- **To monitor large updraft: we monitor large CAPE, other stability indices, frontal boundaries, jetstream and jetstreaks**



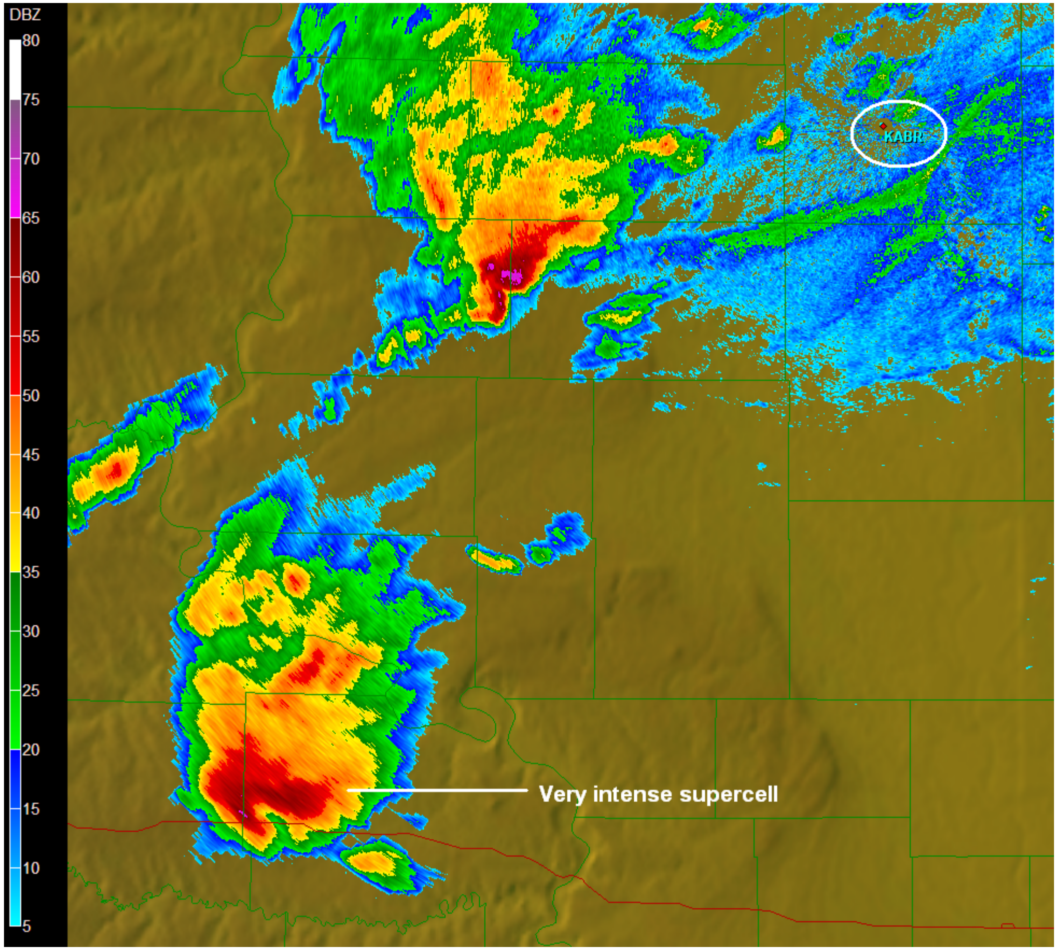
- **SPC Day-1 forecast for the prob. of hail with diameter 1 inch or greater within 25 miles of a point.**
- **SPC Day-2 & 3 forecasts are not hail-specific, just showing probability of severe weather. NWS doesn't issue hail-specific watches. Severe thunderstorm watches are issued for storm that may include hail.**

Detection of Hail: Conventional Radar

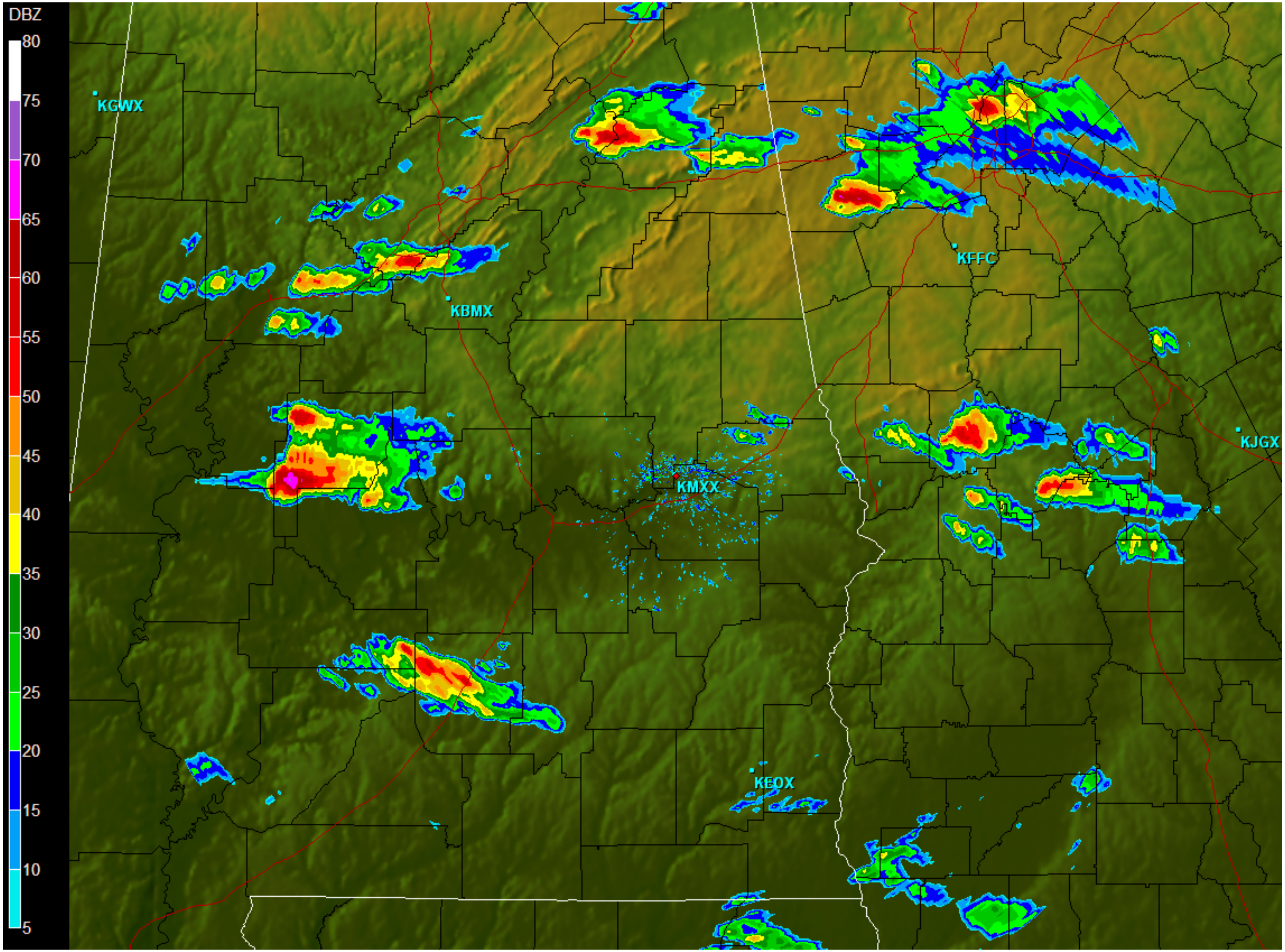
- Rain: usually 20-50 dBZ (sometime could go up to 55 dBZ)
- Hail: a general rule: reflectivity>= 60 dBZ, definitely hail; 50-55 dBZ, possible hail; ~70 dBZ, large hail.
- Uncertainties: wet hails has greater reflectivity values than dry hails.
- **A flare echo** (sometimes called a "hail spike") is an artifact that sometimes appears on images of radar reflectivity when large hail is present in severe thunderstorms.

Severe thunderstorms over South Dakota, July 23, 2010

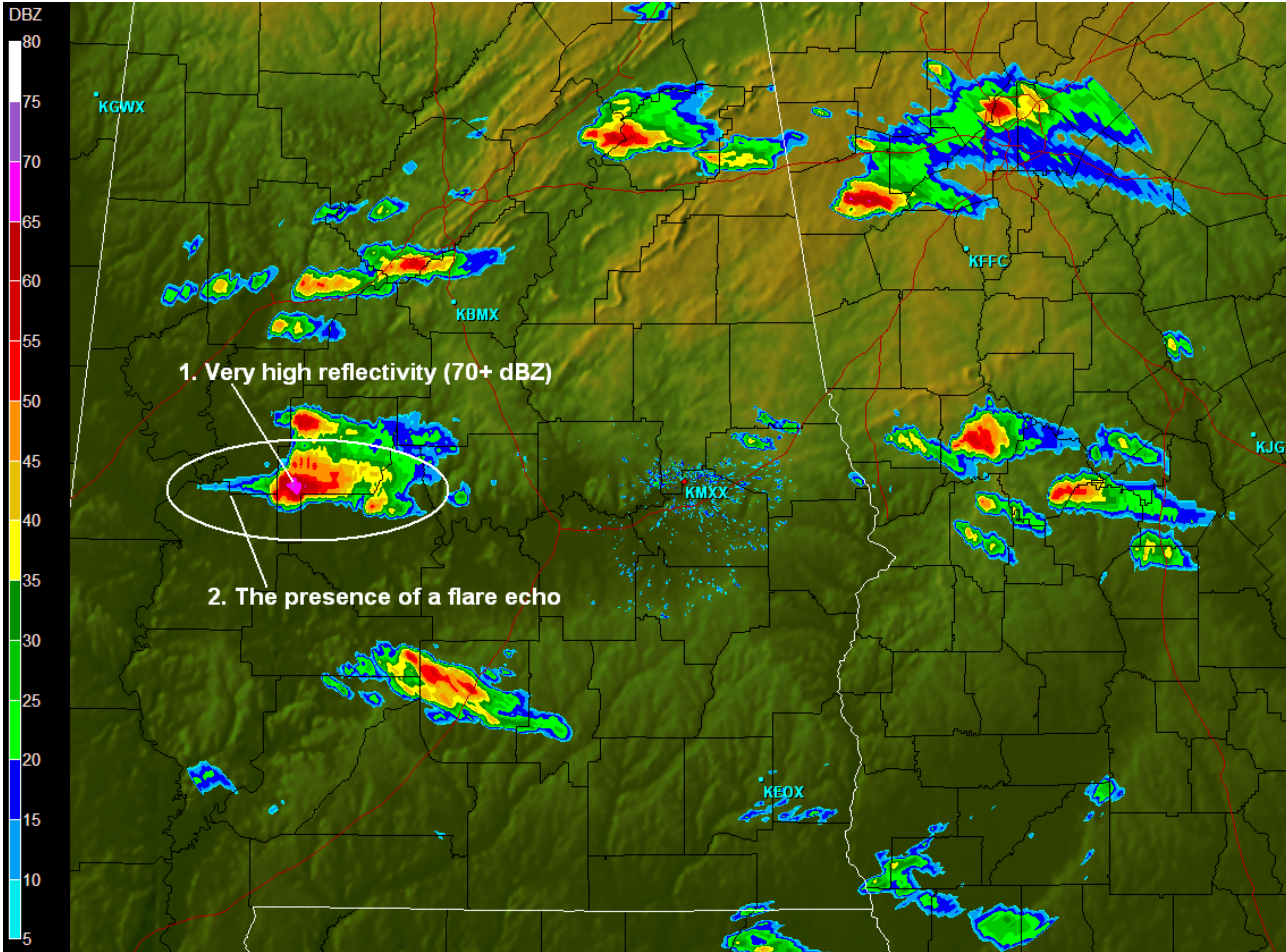
The giant hailstone that fell from a supercell at the town of Vivian, South Dakota, on July 23, 2010, had a record-breaking diameter of eight inches.



Which echo is likely to producing large hail?



Answer:



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KBMX
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KMXX
KJGX
KEOX
1. Very high reflectivity (70+ dBZ)
2. The presence of a flare echo

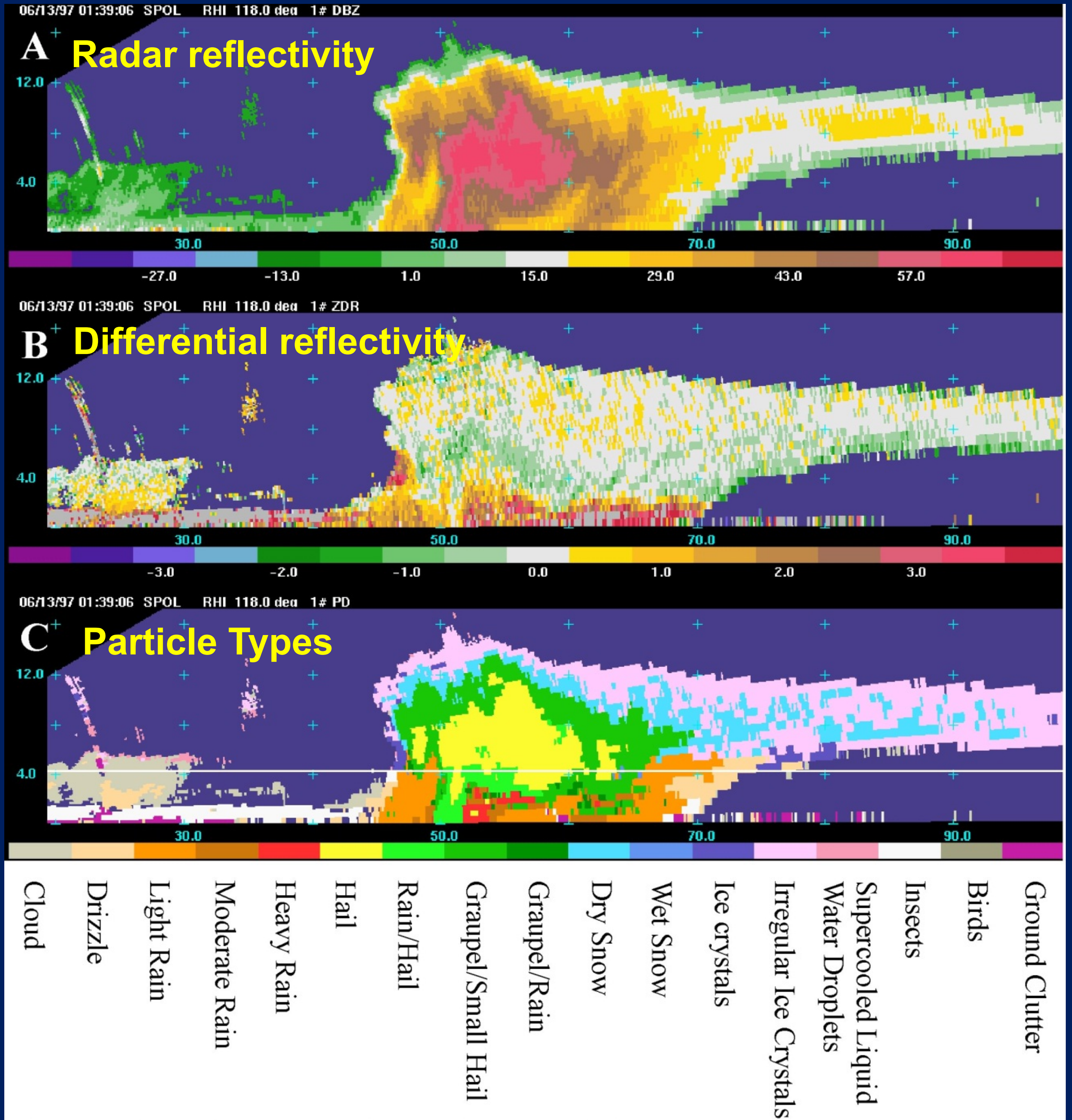
Dual-Polarization (Polarization Diversity) Radar

- **Convectional radar** can not determine hail exactly
- **Dual-pol radar** will improve warnings for hail. Dual-pol radars are capable of distinguishing regions of hail from regions of heavy rain. They measure many parameters related to the polarization state of the transmitted and received radar energy. The set of measurable quantities that can be derived from polarization diversity radars together can be used to discriminate the types of particles (hail, rain, snow, small ice crystals, etc.) within a storm.
- **NWS is upgrading its Doppler radar network** to include dual-polarization function.

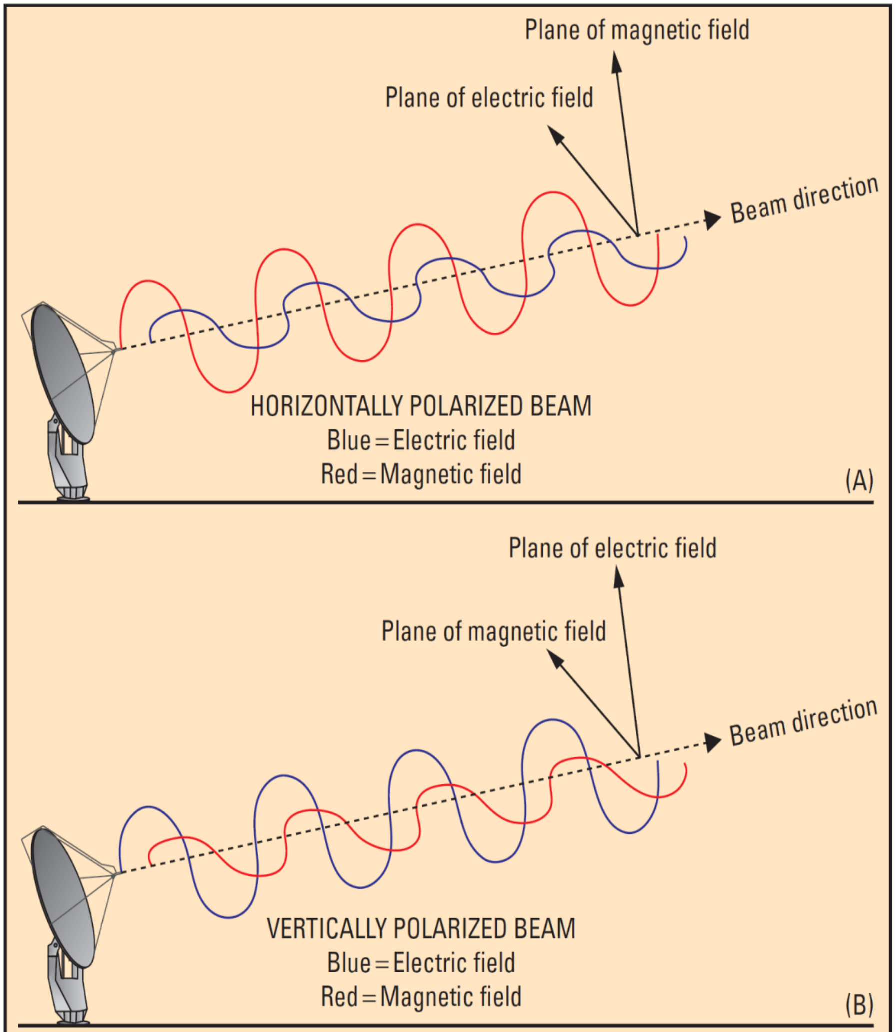
Dual-Pol radar can discriminate different particle shapes & precipitation types

Differential reflectivity: a measure of the shape of the particles within the beam.

Panel (c): hail has high dBZ and low differential dBZ values. Most hail is above 4 km (freezing level). But the downward pointing finger of hail is most likely to reach the ground.

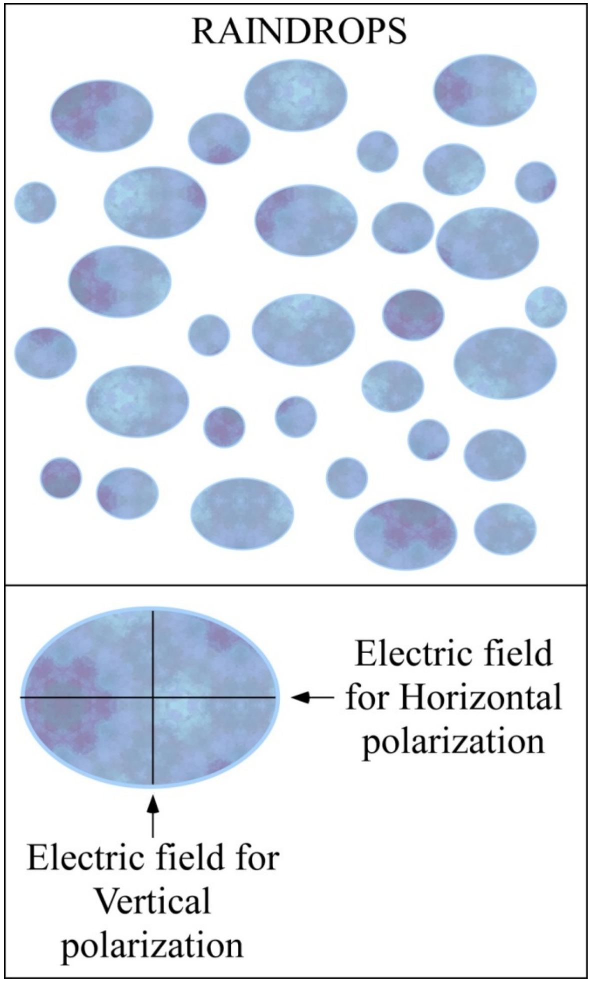


Radar Polarization



- **Radar transmit EM waves** with oscillating electronic and magnetic fields.**E and M fields are perpendicular** to each other and to the direction of radar beam.
- **Convectional radar**: E field oscillates in a plane horizontally (parallel to Earth surface)—Horizontally Polarized (A). Some radars could be Vertically Polarized (B).
- **Dual-Pol Radar**: The orientation of the electric field (polarization) is switched back & forth between horizontal & vertical orientation.
- **Differential reflectivity** is the ratio of the reflectivity measured at horizontal polarization to that at vertical polarization.

Differential Reflectivity of Rain & hail



- **Raindrops:** oval shape. Horizontally polarized reflectivity is larger than vertically polarized reflectivity. Therefore, differential reflectivity is 1-2 dB for moderate rain & 3-4 dB for heavy rain.
- **Hailstones:** some are spherical, others have different shapes. But overall, hailstones fall randomly with no preferred orientation. Therefore, when radar views a large number of hailstones, the differential reflectivity is about 0 dB.

Distribution and Impacts of Hail

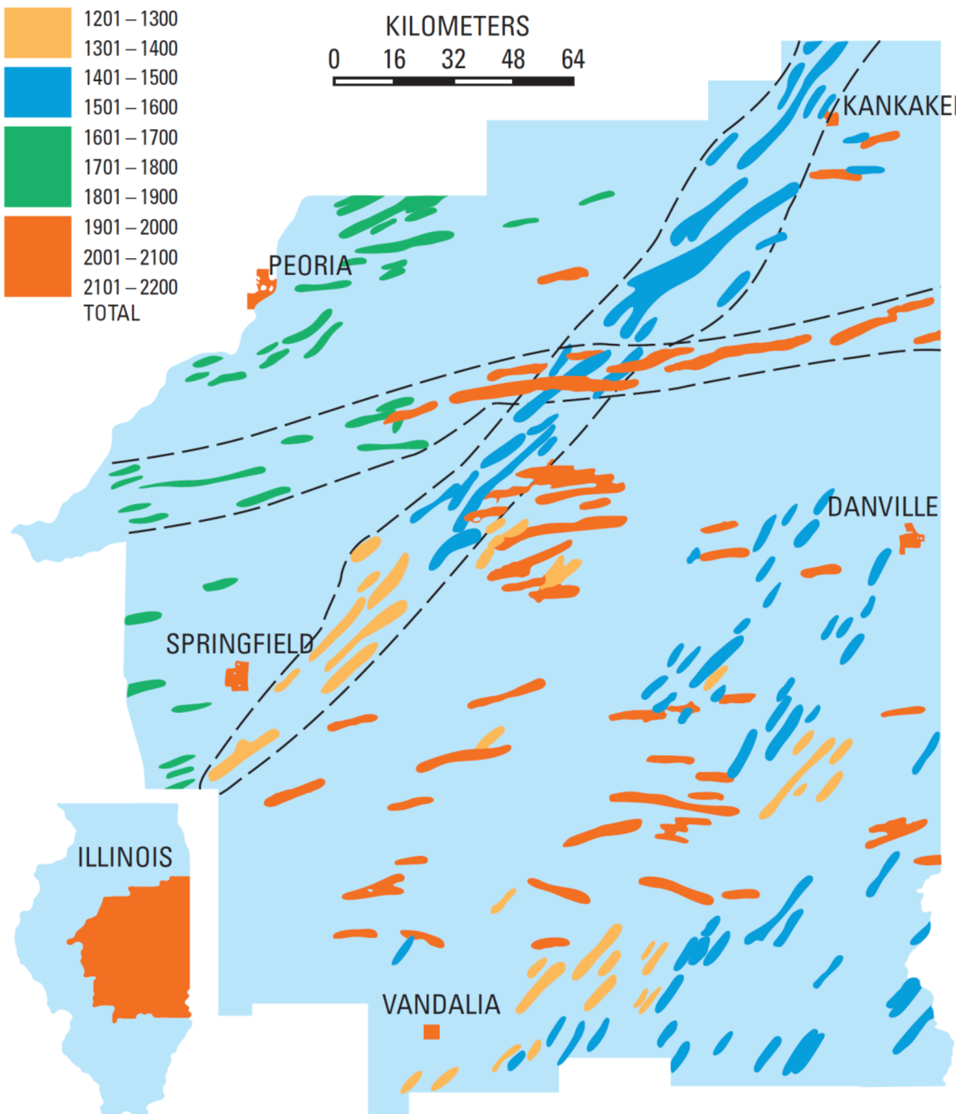
- **Hailfall on the ground**: relatively narrow, a few hundred meters to a few km in width; a few km to 60 km in length.
- **Intermittency**: Similar to tornadoes, intermittent hail is often produced by long-lived supercell thunderstorms, and less often by MCS thunderstorms.
- **Hail damage**: agricultural (crop) damage & structural damage.
- The most damaging hail is most common in the agricultural areas of the **High Plains & Midwest**, least common along the heavily populated East & West Coasts.
- **Hail Alley** includes some large cities, including Dallas, Fort Worth, Oklahoma City, Denver, & Kansas City.

Hailswaths and hailstreaks of two major hailstorms lasting for 10 hrs across central IL (colors are local time of hailfall)

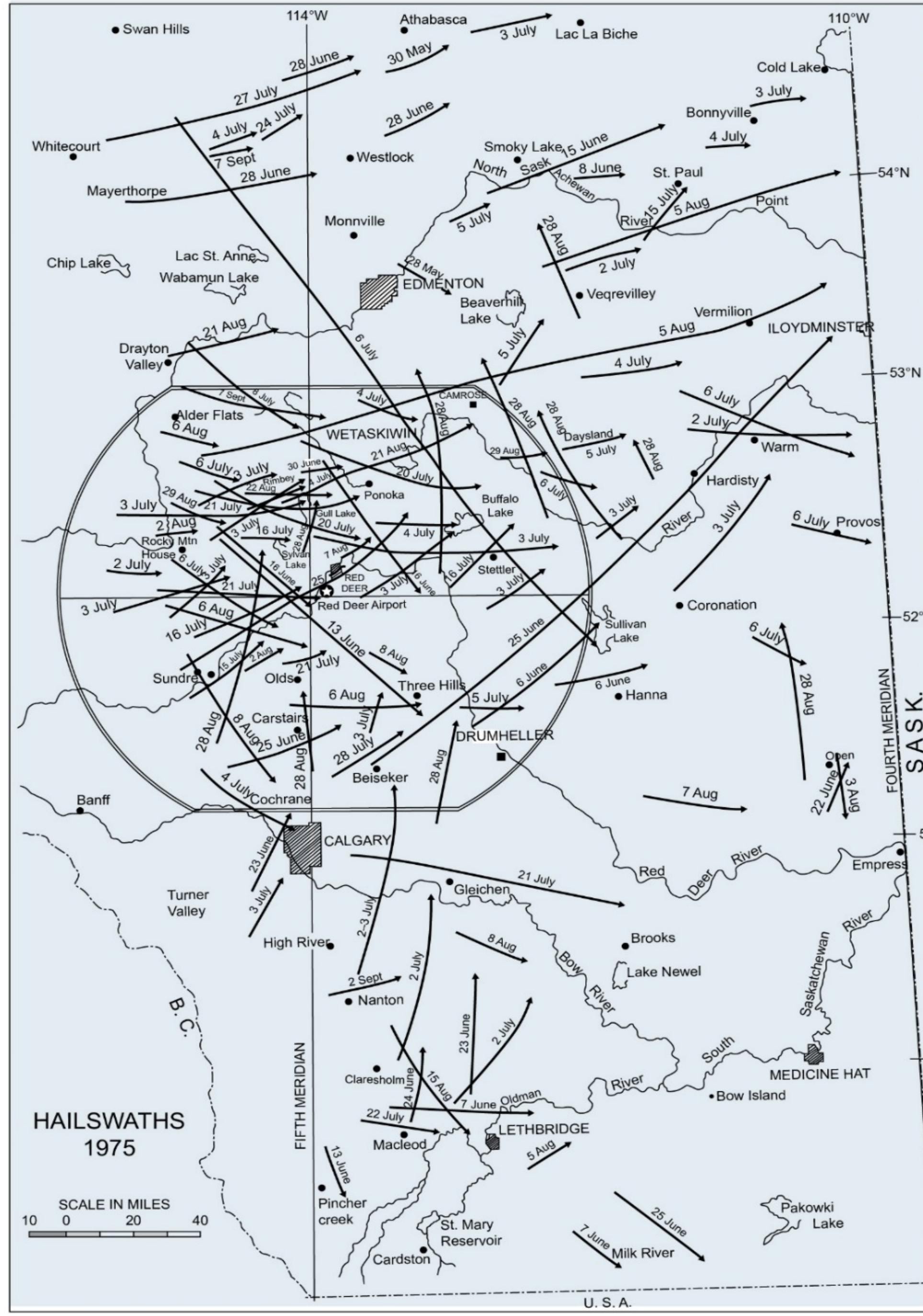
Hailstreaks: the smaller continuous regions of hail coverage shown in colors, typically 1-2 km in width and a few to 60 km in length

Hailswath: areas inside dashed lines, wider and longer area of hailfall than hailsteaks.

Hailswath is a reflection of the track of a individual supercell, while **hailstreaks** are associated with a specific updraft.



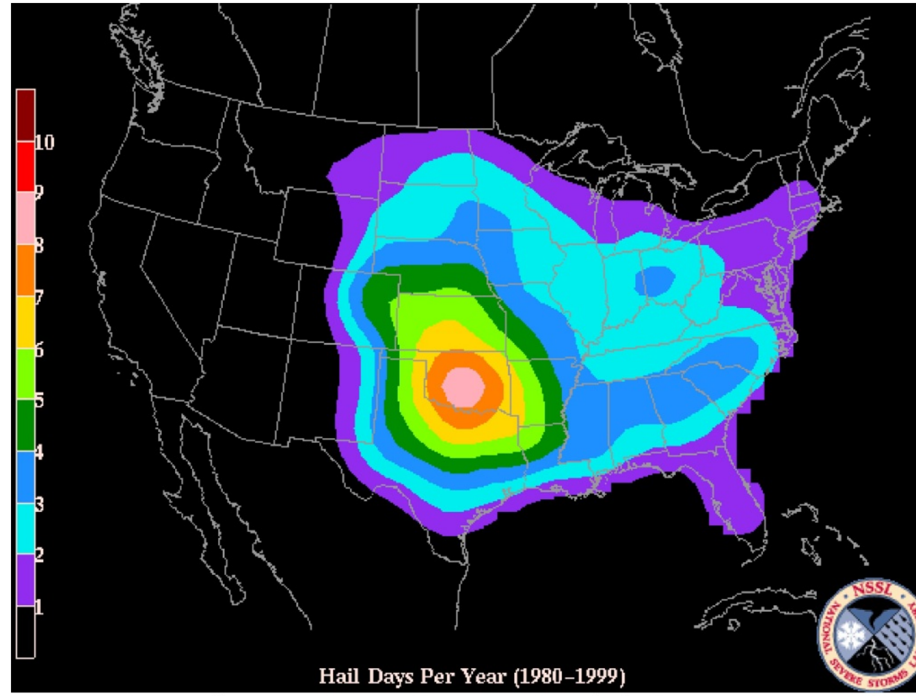
All Hailswaths in Alberta Canada during 1975 summer hail season

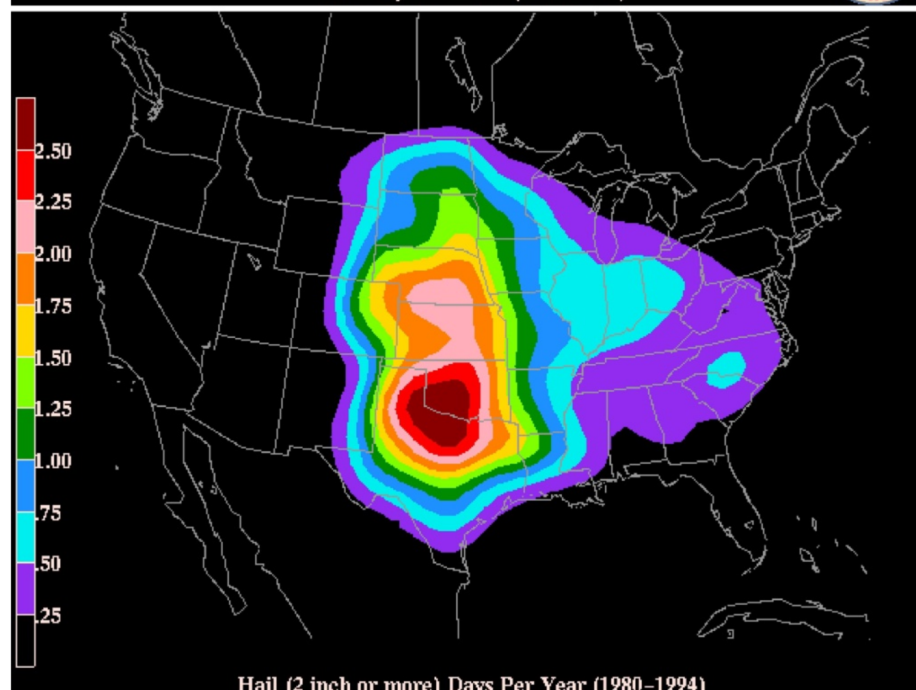


Distribution of annual mean number of days with hail of >0.75 inches diameter (top) & >2.0 inches diameter (bottom)

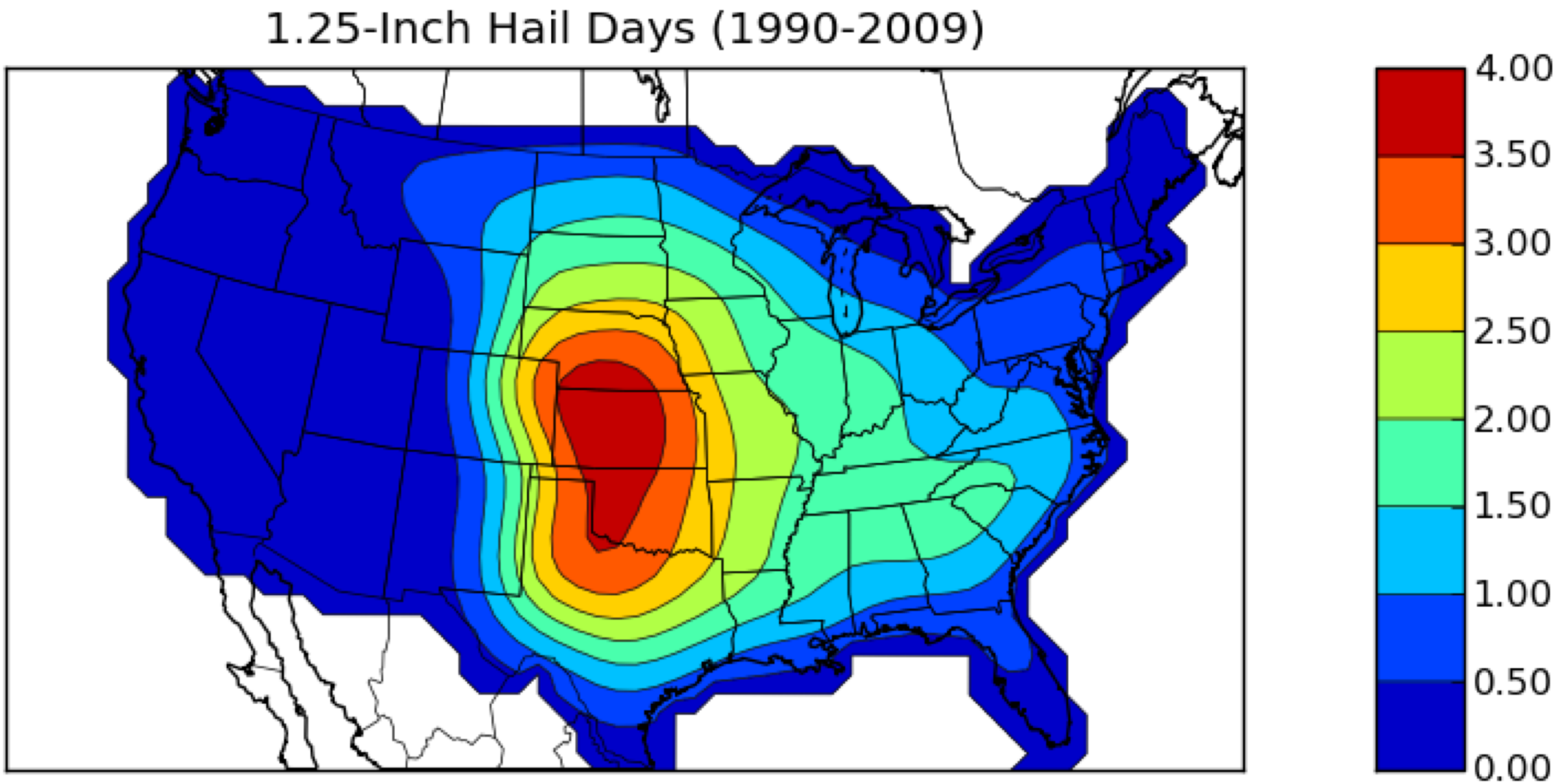
Large hail is most common in the Great Plains states, with maximum frequencies in Oklahoma and Texas.

Hail Alley (from Texas to the Dakotas)



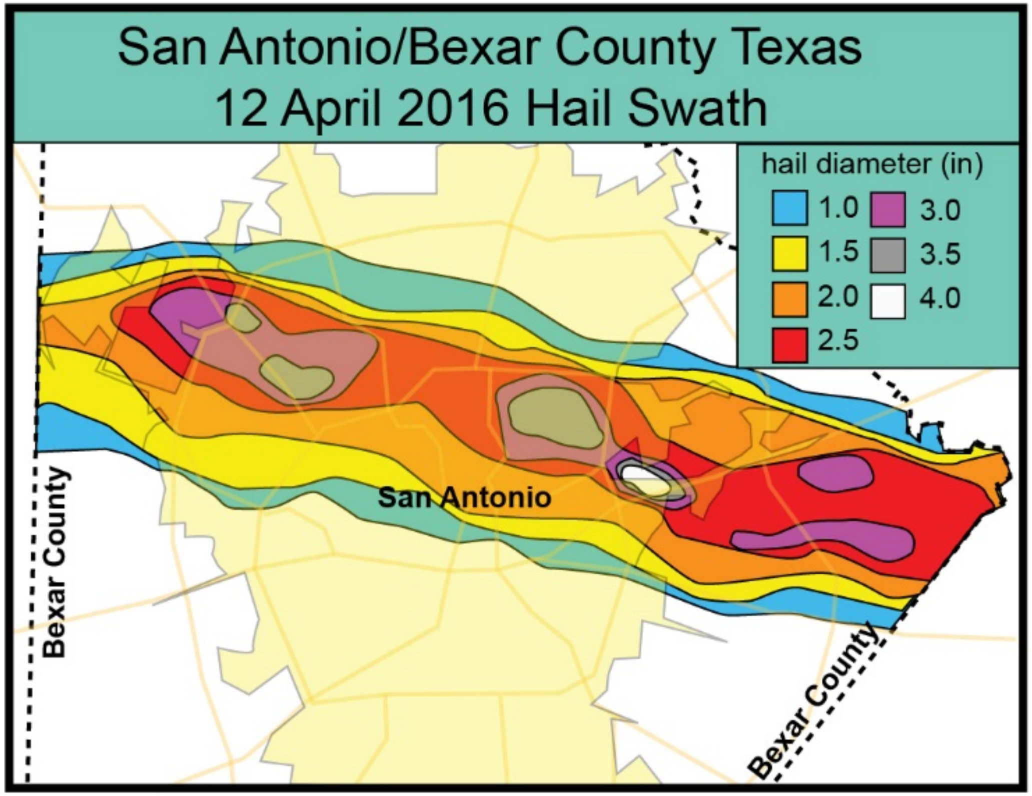


Newer Statistics: Distribution of the annual mean number of days with 1.25-in diameter (or larger) hail within 25 miles of any point, based on data from 1990 to 2009.



Historical Hail Case: San Antonio's Billion-dollar Hailstorm of April 2016

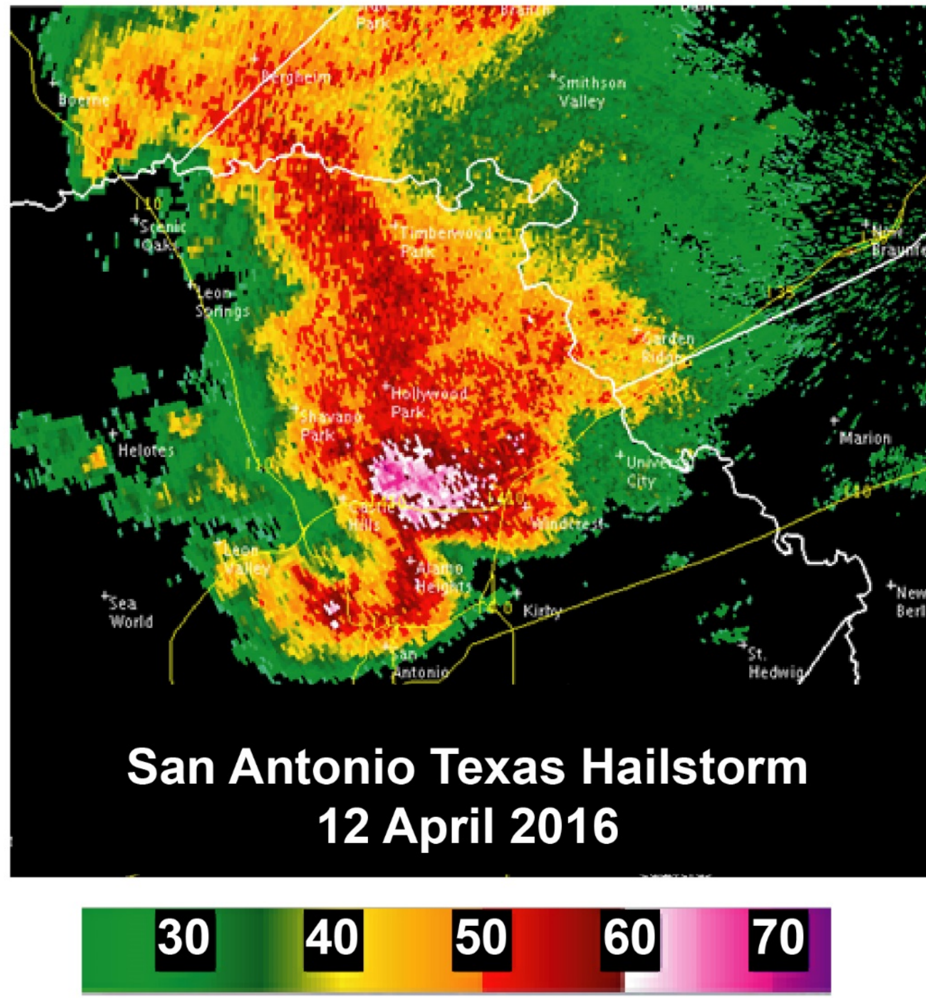
- In April 2016, south-central Texas experienced severe hail outbreaks on several occasions: 12, 17, and 25 April. Total more than $2 billion in property damage. The most damaging of the storms struck the San Antonio area on the evening of 12 April.



- The width of the area that experienced large hail (exceeding 1 inch in diameter) is exceptional, ranging from 8 to 10 miles across. The hailswath is continuous (also a hailstreak), but was produced by a single supercell. The length of the swath exceeded 40 miles. Hail diameters exceeded 3 inches in the pink areas and 4 inches (softball-sized) in several streaks embedded within the swath. There were several reports of hail sizes of 4 1⁄2 inches.

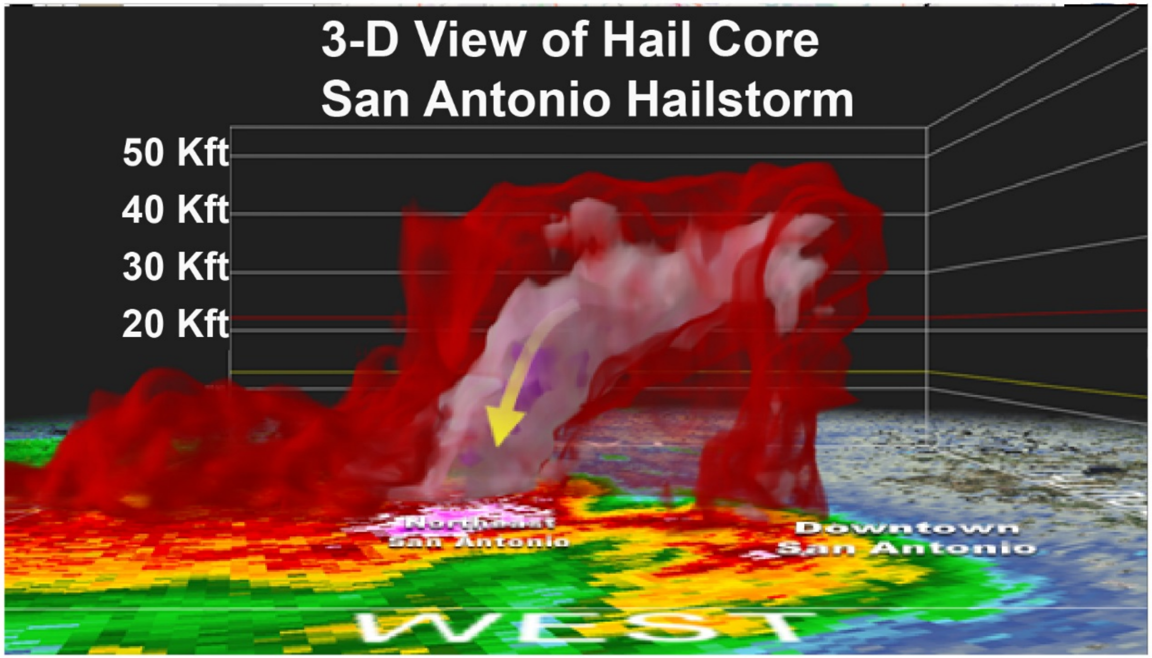
San Antonio Hail Case: Radar Images

- A massive supercell
- **Reflectivities as high as 70 dBZ** (pink shades) are where the large hail was falling.
- **Heavy precipitation** is associated with the RFD south and west of the storm center.
- The leading edge of the RFD has the shape of a **mini cold front.**
- The clear “notch” immediately north of the RFD is the updraft. The large hail is falling adjacent to, and immediately to the north of, the updraft.



Radar reflectivity (dBZ)

San Antonio Hail Case: Radar Images



- The bounded weak-echo region is strikingly apparent, as is the area of large hail falling immediately north of the updraft. The updraft coincides with the notch in the radar reflectivity map, which is shown at the base of this figure. The top of the storm reached nearly 50,000 ft, which is exceptionally high for an early-season thunderstorm. The updraft's large depth, together with the high moisture content (mid-60s °F dewpoints) of the inflowing air, enabled the growth of the large hailstones.